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The Windbreak as a Farm Asset

WINDBREAKS are a farm asset. They tend to prevent the soil from drying out quickly and "blowing", they protect grainfields and orchards from mechanical injury, and to some extent they conserve moisture by reducing winds and so benefit the growth of crops. A belt of trees around the farm buildings protects them from extreme winter cold, as intensified by the wind, and by its shade and verdure in summer makes the farm a pleasanter place in which to live. The windbreak may also be a source of wood supply for use on the farm or for sale. This bulletin explains the general principles of protection obtained through planted windbreaks, the good and bad effects which may be expected therefrom, what species should be planted where only the hardiest succeed, and the care needed to maintain healthy tree growth. For more specific information on planting methods and other details, the agricultural experiment station or State extension forester in your own State should be consulted.

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THE WINDBREAK AS A FARM ASSET

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NEED FOR WINDBREAKS IN THE OPEN PLAINS

SINCE THE OPEN COUNTRY of the prairie-Plains region[1] was first settled and developed, lack of trees has been severely felt. The clear sweep of the winds across the flatter plains has always been a great hindrance to agriculture, for the soil is dried out quickly by evaporation, snow is swept into the low spots where it is least needed, and with long-continued cultivation many of the topsoils have lost the rich heritage of prairie humus which bound them together and have begun to blow or move about under the force of the wind in an alarming way. Small-grain and corn crops are frequently lodged and severely damaged by the more violent storm winds of summer; and fruit trees, of importance in the domestic economy of each farm, are injured by wind breakage or by wind damage to flowers and fruits.

The early settlers from Europe and from the eastern portion of the United States, unaccustomed to the bareness of the Plains, planted trees extensively. Farmsteads were protected, in the majority of cases, throughout the region, and larger groves were planted under the stimulus of Federal and State bounty laws. In some sections where soil blowing occurred in the early years, extensive field areas were given protection through belts and hedges. But later, especially during the land-boom years following the World War, planting

[1] The region included in this term and in the following discussion might be defined as the open or naturally nontimbered country from central Iowa to the Rocky Mountains, the eastern boundary of which runs northwestward through western Minnesota, and southwestward from central Iowa to north-central Texas. Technically this area includes some rolling tall-grass prairie and some flatter short-grass plains. The portion of the Plains roughly between the one-hundredth meridian and the Rocky Mountains contains numerous areas where trees can be grown only with the greatest of care, in parklike formation requiring permanent cultivation, and such areas can hardly be considered to come within the scope of this discussion. They have been given special attention by the Bureau of Plant Industry and the Forest Service in Farmers' Bulletins 1554 and 1603. Although the list of tree species included in table 1, page 19, is designed primarily for use in the six States indicated and would not be identical for use outside of the Prairie-Plains region, much of the other material in this bulletin is applicable elsewhere in the United States.

in the prairie-Plains region decreased. The earliest and most extensive groves aged and weakened. These changes, added to the effect of the droughts which have occurred recently in every section, have greatly reduced the tree population.

It is an easily demonstrable fact that farmstead and field can be greatly improved for man, beast, and crop by protection from wind; and that farms having adequate protection by means of groves and trees command appreciably better prices than similar farms without these assets. A new effort should be made, through both individual action and public participation, to restore and extend the tree growth. It is the special purpose of this bulletin to recommend systematic, thorough, and extensive planting for the protection of cultivated lands, as well as for home beautification and shelter.

The usefulness of windbreaks has been amply demonstrated in other parts of the United States. In numerous coastal regions, along the Great Lakes, and along the Columbia River in Washington and Oregon, trees have been planted to hold in check and give protection against encroaching dune sands; in the fruit-growing valleys of western Colorado, and in the citrus orchards of California, to protect orchard trees, and to conserve precious irrigation water against the drying effect of mountain-to-valley winds; from southern Minnesota to Indiana and eastward, where peat soils receive enough moisture to make their cultivation highly productive, to keep these featherweight soils from blowing away; and in many rich but sandy basins and river valleys, to hold the soils in place during periods when the surface is dry.

In the Plains region, the growing of trees where average precipitation is barely enough for safety of crops presents difficulties; trees do not attain so great a size, age, or protective capacity as in regions of greater rainfall; here there is a more universal need for windbreaks than elsewhere, except in the similar extensive plains regions of Europe and Asia. It is because of the difficulties met in our middle-western prairies and plains that this bulletin offers specific recommendations for that region. Elsewhere, a much greater variety of methods and choice of species may give the desired results without the necessity of hewing so closely to the line.

WHAT IS A WINDBREAK?

In the strictest sense, the term "shelterbelt" should be used to characterize a windbreak of trees as distinguished from fence, barn, or other more artificial barrier to wind; but for the purposes of this bulletin both words will be applied to tree growth of sufficient extent to present a real obstacle to wind.

The most generally effective windbreak is a reasonably long belt of trees that affords protection from winds of various directions through nearly half of the complete circle. Such a belt fulfills the purpose of field or home protection much better than the small group or block of trees or a short L-shaped belt. Throughout most of the Plains region it is particularly important for crops to have protection continuously through the summer from all winds of southerly origin. The area protected by such a belt, as shown in

figure 1, is triangular in shape but until it reaches out to about 12 times the height of the trees, as in the large diagram, the possibilities of distance protection are not being utilized. Thus, the value of the protection afforded increases as the square of the length until the latter is at least 24 times the height. Under these limitations, if 3 rods or 49.5 feet be taken as tree height, the following areas, very conservatively estimated, should show 10 to 15 percent reduction in wind at their extremes:

Windbreak length:	*Area protected*
6 rods	9 square rods.
12 rods	36 square rods.
72 rods	1,296 square rods, or 8.1 acres.
160 rods (one-half mile)	4,464 square rods, or 28 acres.

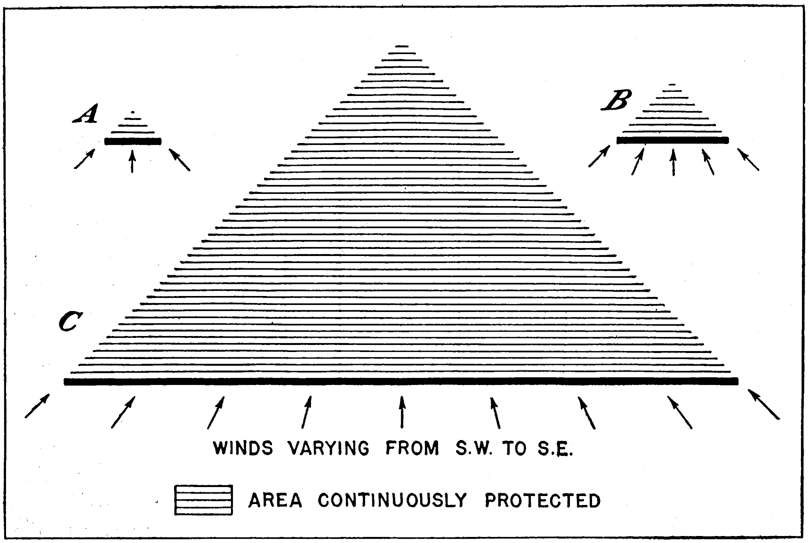

FIGURE 1.—A windbreak must have great length to protect effectively any considerable field area.

This diagram covers only such conditions as might reasonably occur in the summer with the wind in a general southerly position, but shifting from SW. to SE. Only a triangular area on the north (*A*, *B*) is then so protected that crop benefits can reasonably be expected. Until this triangle reaches out to 12 times the height of the belt (*C*) the possibilities of distance protection are not being utilized.

Although somewhat changed, these general relations will hold for a wide variety of wind directions, provided the long windbreak is oriented to catch the more important winds "broadside."

It is desirable to carry such a row or belt of trees on the farm as far as possible without a break, if the maximum benefits from each unit of planting are to be secured, since there are points at the end of any belt, as at any gap in the tree wall, where the wind has a little more than normal force. It is desirable to have as few "ends", or even "gaps", as possible in the barriers. At points where the trees must end, and especially on ground where soil blowing is rather easily started, the belt should be tapered off to low shrubs and if possible a small area of sod.

HOW A WINDBREAK PROTECTS

CHECKING WIND MOVEMENT

Although windbreaks have values other than that of protection, as in shading buildings or cattle pens and in their aesthetic value, it is chiefly from the standpoint of their mechanical action in the reduction of wind movement that they are considered here, including such secondary effects as reduction in evaporation, influence on air temperatures, and control of the drifting of snow or soil. By erecting windbreaks, relatively quiet "pools" may be created in the air just above the earth. While these "pools" are comparatively small, yet they extend, with a gradually increasing current, for a considerable distance from the windbreak, and a small reduction in current may carry over to another windbreak as much as one-fourth to one-third mile distant.

The effectiveness of a windbreak depends upon how nearly impenetrable it is. Tree windbreaks never provide an absolute barrier to the wind, nor is it desirable that they should, since a "tight" barrier sets up eddy currents which are more serious than a small amount of air leaking through. Movement of the air on the leeward side is never completely stopped but only greatly reduced. As windbreaks of cottonwoods or similar hardwoods age, wide openings appear between the trunks, and more wind gets through near the ground than higher up. Such windbreaks can be made efficient only by underplanting or sideplanting with smaller trees or shrubs.

An ideal windbreak for checking wind currents has the shape of an earth dam (see cover design). In the central rows are planted the tallest-growing trees, such as cottonwood; on either side, rows of shorter trees, such as ash, elm, and locust; and outside of these, evergreens and low bushes. Such a windbreak is not easily penetrated, especially at the base, where it is thickest and where it is most important that the wind be stopped.

A windbreak of moderate effectiveness reduces the velocity of a 20-mile wind striking it squarely, for a distance equal to about 30 times the height[2] of the trees. About one-fourth of the protected area is usually on the windward side and three-fourths on the leeward side. Thus, trees 65 feet high usually reduce the ground wind by 10 percent or more for a distance of 30 times 65 feet or 1,950 feet—over one-third of a mile. Beyond this may be a measurable though insignificant influence for several additional "heights" in both directions.

The degree of protection shown in the middle portion of a moderately long windbreak varies, of course, with the distance out from the barrier, and the position of the greatest effect depends upon the height of the densest foliage or greatest resistance. A slat windbreak was constructed of 6-inch boards with 12-inch spaces in the lower half, but only 3-inch spaces in the upper half, thus somewhat resembling old trees with very few limbs near the ground. Figure 2

[2] Because of the fact that the effects of all windbreaks are similar at distances measured roughly in equal multiples of the height of trees, tree height is used as the unit of horizontal distance measure in comparisons of unlike situations. For example, the length of a belt is said to be "10 times its height", or a certain effect is observed at "15 heights from the belt", and so on.

illustrates how the wind-reduction benefits were distributed, the field of this barrier narrowing down almost to a triangle with a somewhat shifting wind of 13 miles per hour which "cut in" on the sides at times. The lowest velocity here noted was 47 percent of the open-field velocity and was at 5 heights from the barrier. With greater density near the ground this low point moves in much closer.

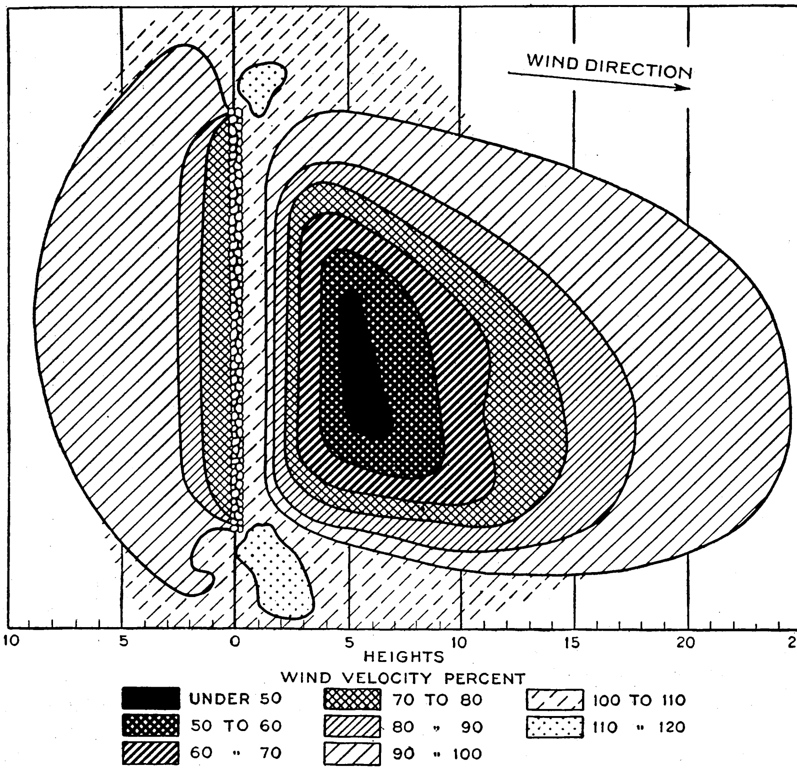

FIGURE 2.—The actual field of protection of a windbreak 19 heights long, with an average density of 50 percent but more open in the lower than in the upper half. The air pushes through the opening at the bottom and shoots upward on the leeward side. The wind was measured 16 inches above ground.

A very dense tree belt, similar to the one illustrated in figure 3, allows only about 23 percent of open-field velocity close in, and 80 percent at 20 heights, with winds from 20 to 25 miles per hour. Such a belt reduces the wind at 30 heights to about 90 percent. On the other hand, an open cottonwood belt, such as that illustrated in figure 4, reduces the ground wind no lower than about 95 percent of the open-field velocity near the trees, although farther away it may drop to about 80 percent before beginning to rise.

The value of any windbreak in checking mild breezes is negligible, but high winds may be reduced in the protected zone slightly more than indicated by the figures above, at least with belts of high density. Beyond a certain point, however, eddies may tend to counteract the more complete stoppage effected.

PROTECTING CROPS FROM BLOW-DOWN

It is by no means uncommon for violent winds associated with the thunderstorms of midsummer to level or lodge growing crops so that,

FIGURE 3.—Both thickness and height are necessary if a windbreak is to protect a large area. The tall cottonwoods in this South Dakota windbreak are backed by dense and shorter ash trees—not a perfect design, but much more effective than the average.

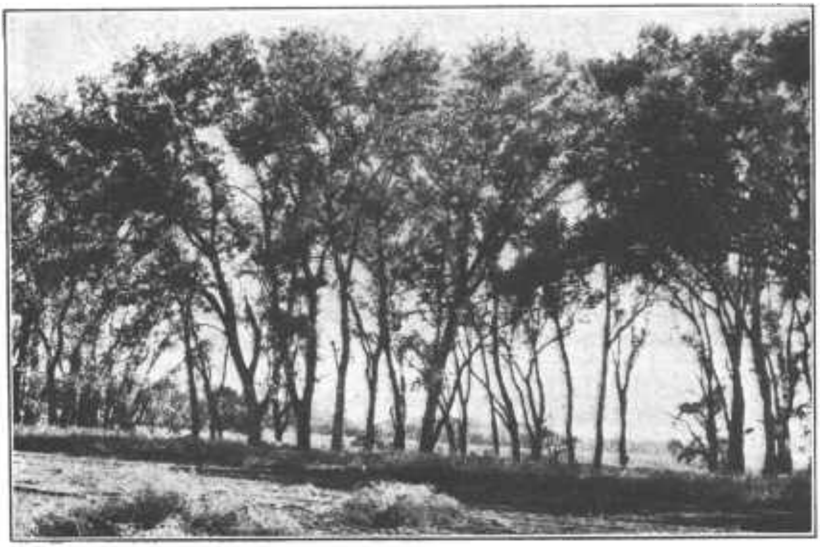

FIGURE 4.—Many groves in the Plains region have been so thinned by age that their windbreak value is largely lost. This cottonwood belt in Kansas, 10 rods wide, is scarcely more effective than a single row of trees.

even though they be mature or mature later, harvesting is very difficult or impossible. Windbreaks cannot entirely prevent such damage unless placed quite close together between fields; yet it is important to note that the higher the wind velocity, the greater is the percentage reduction in that velocity effected by a good windbreak, and the

farther into the field is an appreciable effect felt. A specific measured example of the mechanical protection of crops will show how valuable such protection may be.

In southern Minnesota in 1908 a windbreak 80 rods long and about 28 feet high along the side of a cornfield afforded complete protection for a strip about 10 rods wide from a wind blowing at 50 miles an hour. Beyond this strip the wind blew down half the corn and bent the remainder halfway, the greatest damage being farthest from the windbreak. The corn was in the milk stage at the time and did not produce more than a third of a crop on the damaged area. On the protected portion the total saving was 260 bushels, or the full crop of 6 acres, whereas the windbreak occupied only 2 acres.

PREVENTING SOIL BLOWING

The reduction of ground winds is directly important in every region where recent experience has shown a growing tendency for soils to be blown, as during the widespread dust storms of 1934 and the spring of 1935. There is as yet no experimental basis for stating to what degree the wind erosion of soils may be prevented by windbreaks,[3] yet the very old custom of planting windbreaks in localities where the soil is easily eroded by wind plainly indicates appreciation of their value. Protection has been obtained in vulnerable erosion areas by not very extensive or very systematic windbreak planting, as in sandy portions of the Platte Valley. On the sandy cotton lands of western Oklahoma, where sand blown along the surface of the ground may cut off the young plants two or three times in a single season, frequent windbreaks are about the only means by which a crop can be grown.

Experience and observation would indicate that it requires a wind having a velocity of at least 25 miles per hour to cause severe wind erosion, and generally only in quite extensive openings where the wind "gets a good sweep." The exposure of large continuous areas to a uniformly strong wind is an important element in developing soil erosion of considerable proportions, and therefore the effect of successful windbreaks in creating relatively calm pockets of air should be a helpful factor in checking such development.

Nevertheless if even a very small farm or grazing area is sufficiently abused, it will blow regardless of the conditions surrounding it. There is no palliative for such land use. Erosion in such cases is as impossible to prevent as erosion in dune sand, where nothing less than a complete cover of vegetation will suffice.

CONTROLLING SNOW DRIFTING

In the northern plains, drifting snow is a source of many hardships. Control by windbreaks is almost entirely a matter of proper placement with reference to all lanes of travel and topographical features. Placement, in turn, is largely determined by the type of windbreak—open or dense.

A single row of trees, unless it consists of conifers planted close

[3] A very difficult thing to measure experimentally for general application, since in addition to wind velocities so many factors affecting the condition and vulnerability of the soil are involved, such as fineness and dryness of the soil itself, condition of cultivation, roughness of surface, etc.

together, is rarely dense enough to stop fully a winter wind. Most of the snow is blown through the thin screen of trees and deposited on the leeward side. This result may be desired on high-lying fields which otherwise are often swept bare; but it is evident that the single row may do harm if placed too close to a yard or highway.

A wide belt of trees, usually accumulating a large drift on its windward side but permitting no drifting snow to pass entirely through or over it, may safely be placed at the edge of the yard or cattle pens, the windward edge reaching to a distance equal to three or four times the height of the trees, and generally at least 100 feet.

In the northern plains and Canada, the "snowtrap" windbreak is quite popular and practical, requiring fewer trees than the wide belt

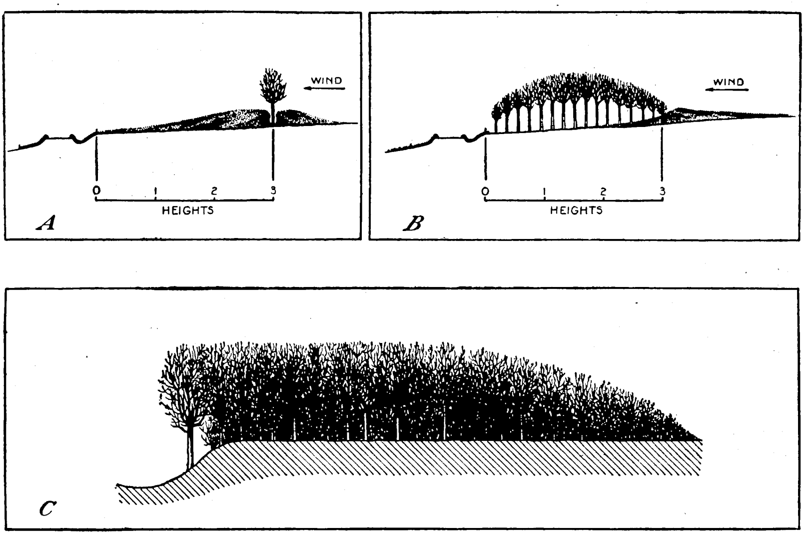

FIGURE 5.—Placement of windbreaks of different types to control drifting on roadway or other areas, when drifting winds are generally from one side. *A*, Cross section of single row. *B*, The cross-section of a wider belt takes no more room and is more certain to deposit snow at a safe distance from the roadway. *C*, Wide belt in longitudinal section, indicating how "streamer" drifts around ends may be guarded against by (right) tapering the end down to low bushes or (left) cutting off in a depression.

and permitting the use of the deposit area for gardening and such purposes. One or more rows of trees give wind protection close to the yard or buildings. To the windward of these is a wide opening; then a single row of trees to catch the first force of the storm. Most of the drifting snow is deposited between the two rows.

The same principles apply in the locating of windbreaks along traffic lanes. If a single-row snow fence is erected to protect a cut on a road or railroad, it is placed far enough back to give ample room for snow deposit between it and the cut. A reasonably dense, broad belt, however, may safely come to the edge of the cut. These points are illustrated in figure 5, *A* and *B*.

Briefly stated, the prejudice against windbreaks as factors in blocking roads arises generally from poor and irregular protection, or from ill-considered placement of heavier windbreaks. Scattered trees along the road help much in forming drifts unless trimmed

very high. Poor or single-row windbreaks should be kept well back from roads.

If drifting is caused on highways by good groves or wide belts on the north or windward side, it will be at the ends of such belts, where high wind velocity may tend to make a single "streamer" drift. To avoid such trouble, the end of the belt should be made to fall in a depression, or, barring this, the end should be tapered out (see fig. 5, *C*), and reduced to low shrubbery, which will trap some snow but let the wind pass over and "sweep" the road where a drift might form.

More trouble is likely to be caused by breaks to the south of roads. A windbreak fully effective in stopping wind will collect a drift of snow on its windward side, and therefore should not approach closer than 2 rods to the road shoulder in any region where drifting is a matter of consequence. Even low shrubs may easily, because of their dense growth, cause windward drifts to fill the road ditch. A plan considered favorably by highway officials of a northern State would encourage windbreaks to be set back a few rods from the roadbed, with the property fence at the edge of the trees, and would permit the landowner to utilize the land between the trees and the foot of the road embankment, partly on the right of way. Such an arrangement is especially desirable for either side of a north-south road which may thus be kept open to be swept by north winds.

Even where snow drifting is infrequent, the long shadows of the trees on the south side of a road are important factors in keeping road surfaces icy throughout the winter, and in preventing their drying in the spring. Windbreaks planted on the south side of roads should be set well back, or sloped back, with only short shrubs near the road and taller trees at a distance. If the road is to be completely sunned in midwinter, trees which will be 50 feet high when mature should be set back from the south shoulder the following distances:

	Feet
Northern Oklahoma	85
Central Nebraska	107
Central North Dakota	145

Taller trees should be set back proportionately. Trees placed on the edges of roadways for summer shade are very questionable assets in the northern region.

REDUCING EVAPORATION

The reduction in ground winds by a windbreak capable of affecting in some degree a large area results in corresponding though much smaller reductions in the *rate* of evaporation directly from the soil and from the leaves of plants. In some cases the expectancy of better crop yields is fully realized thereby, while in other cases the conservation of moisture is, of necessity, of such a temporary nature that there are no practical benefits. Without attempting to define the evaporation process in technical terms, it is possible to make clear by a familiar analogy the failure of wind protection to produce practical results.

Every good farmer uses cultural practices which are in part designed to hold the moisture in the soil for the use of crop plants,

but he knows that mulching and cultivation of the surface cannot entirely prevent the loss of soil moisture, but will only retard the process so that the supply lasts longer. If drought prevails for a long time, the entire useful supply of soil moisture may be lost, despite surface protection. This is no criticism of mulching but merely signifies that even the best possible methods are ineffective under extreme conditions. Exactly the same thing is true of protection by means of reduction in wind velocity and resultant evaporation. In extreme drought, such as that of the past few years, the beneficial effects of windbreak protection will have little opportunity to operate.

Under slightly more moderate conditions a striking effect may be produced by the windbreak, although it will not necessarily insure profitable crops. If fully exposed parts of fields dry out too soon for any crop to mature, the protected portion may yet have enough moisture to mature a partial crop, which by comparison will loom very large.

On the whole, it appears that reduction of evaporation produces most substantial benefits when rains are fairly frequent, yet not so abundant that crops have enough moisture for their best development, and in northern rather than in southern farming regions. Such crop conditions will be treated more specifically later. It is as a demonstration of northern conditions that most available results in the Russian steppes must be viewed.

EFFECT ON TEMPERATURES

Although large forest areas cool the air within them during the day, and this cool air is sometimes carried for some distance to the side, windbreaks in the prairie-Plains region are rarely extensive enough to have this effect, and generally have the opposite effect on the area to the leeward, even when the air blowing over the tops of the trees is considered. A series of observations under a strong, hot, dry wind blowing over a belt of ash 290 feet wide showed that both at 5 feet and 40 feet above the ground the air was 1° warmer on the leeward than on the windward side, about 70 feet from the trees.

The effect of a windbreak upon actual air temperature is very slight, and results from failure of the air near the ground, which is warmed more rapidly on a clear day and at night cools sooner, to be mixed through wind movement with air from higher levels.

At a distance of two to three times the windbreak height, where the wind is most reduced, temperatures about 2° higher than elsewhere will be recorded in the middle of clear days, the effect on field crops depending largely on moisture. In 1908, with plenty of rainfall during the growing season for corn, this temperature effect was thought to be the cause of a good many recorded increases in yields near windbreaks. In a dry year the opposite effect might be noted.

Still frosts at night—when a general night calm prevails—are probably not appreciably increased by windbreaks for trees do not greatly increase air stagnation under these conditions. But it is generally conceded that windbreaks surrounding fruit trees or sensi-

tive garden crops should be somewhat open near the ground to permit the coldest and heaviest air to drain away, if possible. In the more general spring freezes, with or without rain, sleet, or snow, damage to fruit blossoms and young garden crops may be modified by a reduction of wind, just as on the leeward side of a fruit tree after freezing storms. At critical periods, protection of orchards from wind has been known to produce outstanding benefits in the amount of fruit set and matured.

These considerations lead directly to the subject of "sensible temperature", which means the temperature which is felt, in contrast to the actual temperature of the air. The difference is often great, and is in most cases increased by wind. In cold windy weather, the protection of a windbreak creates a sensation of warmth by reducing both the evaporation and radiation from the body, although evaporation may then be rather insignificant. The greater bite of a moist winter wind, which has a greater capacity to absorb and carry away the heat of the body than does dry air, attests the importance of radiation and conduction, rather than evaporation. These effects are not questions merely of comfort, but often of life and death to men, to livestock, and doubtless to wild animals living more or less in the open. So obvious is the importance to every living thing of protection from wind in severe winter weather that it would be useless to attempt to set a measure upon the value of windbreaks where they can serve animal life in this way.

One final point under temperature effects of windbreaks deserves mention, namely, their value both in adding to the comfort of homes in windy sections of the country, and in decreasing the difficulty and cost of artificial heating. Engineering data show beyond a doubt that the fuel saving may be real and substantial, for with common types of building material the loss of heat through the wall is about three times as great with a wind of 20 miles per hour as with calm air. Losses of heat due to air entering and leaving through cracks and openings of all kinds, increase in the same way with wind. In the face of such recognized facts, there can be no doubt that a substantial windbreak about the farm home, one extending on two or three sides and containing a good number of evergreens in the outer rows, might save one-third or more of the fuel bill. The cover design of this bulletin depicts such a windbreak.

EFFECT OF THE WINDBREAK ON YIELD OF CROPS

The effect of a windbreak on crops grown near it is not beneficial in every respect and in certain ways is plainly injurious. Trees in a windbreak always spread their roots extensively into the adjoining fields in search of moisture; and they take not only the moisture but some of the nitrogen content of the soil. Furthermore, by shading the ground they may prevent crops from developing properly.[4] The net effect is determined by whether the benefits derived from their influence on wind movement, temperature, and evaporation are greater or less than the injury resulting from the sapping and shad-

[4] Some crops do better than others when shaded. Forage crops, such as timothy, maizes, and alfalfa, are least affected; grains which develop early in the spring, such as oats and wheat, are most affected, and corn occupies an intermediate position.

ing of the ground nearby plus the value of the crops displaced, if more than a single row of trees is used.

Figure 6 shows a cross section of that portion of a field influenced

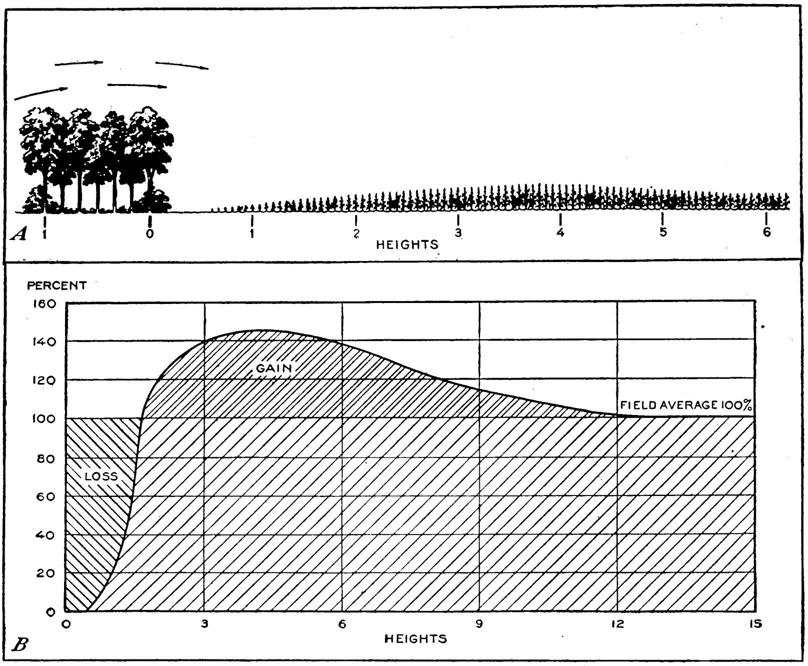

FIGURE 6.—Cross section of a windbreak and protected field, indicating where benefit to crop is commonly found, and also the method of laying out the land in successive strips as wide as the height of the trees. *A*, Windbreak and field crop in true proportions; *B*, diagrammatic representation of the weight of the crop at various distances from the windbreak as determined by small samples at many points, and expressed as percents of the field average. The same diagram could be used to show the yield in different parts of field in bushels per acre.

by an adjoining windbreak. Samples obtained at the greatest distance from the windbreak give what is called the field average. If, as in this diagram, the total gains in yield exceed the total losses up to the nearest row of trees, the net gain may be compared with the field average of crops that could have been grown on the ground occupied by the windbreak. With a single-row windbreak there is no ground not accounted for.

Such crop measurements were made in about 25 fields in Nebraska, Kansas, Iowa, and Minnesota in 1908, and in about 50 fields in South Dakota, Nebraska, and Kansas in 1935, each of the latter protected on one side by a windbreak. Average rather than exceptional conditions were measured,[5] the object being to discover the effect of those influences which are common and affect every annual crop grown.

So far as this evidence goes—and it does not yet cover nearly as great a variety of conditions as it should—the following facts are

[5] The number of cases suitable for measurement is always limited by the need for reasonably good and regular windbreaks and by flat fields wide enough to extend beyond their influence. Comparisons are never made between two fields one of which is protected and the other not, because of the almost certain variance in the cultural treatments of their recent history.

indicated with respect to the chief field crops and may have wide application.

EFFECT ON CORN

As already stated, in a season of drought or other extreme climatic condition no appreciable effect of windbreaks is evident. The greatest net benefit generally coincides with a normal or better growing season. Measurements in 1908 covered about 20 fields on good sandy bottom land or well-watered upland in the eastern halves of Kansas and Nebraska, where field averages ran somewhat above 40 bushels per acre. Rainfall during the corn season was above normal, and at the time it was thought the beneficial effects of windbreaks were partly due to increasing the midday temperatures, an important item for corn in a cool summer. In some cases, very striking benefits from the higher temperatures were noted early in the season, while growth as a whole was lagging.

Most of the fields lay to the north of windbreaks, which ranged from low Osage-orange hedges to tall cottonwood rows and groves. South of hedges only, beneficial effects were noted. To the east and west, in the few cases studied, there was no appreciable increase in growth and certainly not enough to counterbalance the loss near the trees. The gain on the north side was in nearly every instance more than enough to pay for the damage done near the trees. Windbreaks lying between two fields, with possible benefits on both the north and south sides, would have produced a net gain in the average case sufficient to pay for the ground occupied by a fairly wide belt. For example, with cottonwoods 60 feet high, a belt 100 feet wide from outside row to outside row would have "paid for itself" in this season; with Osage 25 feet high, a space 45 feet wide could have been occupied by the trees with no net loss of crop when comparison is made with unprotected fields. Because, in the case of single rows, no such space is occupied according to the method of measurement and calculation employed, it was computed in one rather unusual case that a half mile of single Osage hedge had produced an additional corn yield worth more than $50.

In late July 1935, corn was badly damaged by the heat and lack of rainfall over a good deal of this same territory. In the worst areas, fields with and without protection yielded no corn at all. With less extreme conditions, resulting in average yields of about 20 bushels per acre in the fields observed on sandy land around St. John, Kans., some benefit was noted in nearly all cases. Most of the fields measured were to the east or west of 50-foot rows or wide belts. Possibly because of southeast winds, gains on the east side did not balance losses—the sapping zone being wider than in the moist year 1908. To the west they were more than enough to balance losses to the base of the trees. Taken together, both sides justified north-south windbreaks of two or three rows of trees. One field each, to the north of a row of mulberry and to the south of a cottonwood grove, showed benefits of about the same degree as those noted in 1908, although field averages were only 18 bushels of corn.

On the loess uplands of Clay County, Nebr., in the same season, a large number of measurements in all directions from Osage hedges

showed generally some slight gains in the best-protected parts of fields, but since the growth was very spotty and uneven, it is doubted whether it can safely be claimed that the hedges, on an average, paid for themselves in this season when yields were only 8 to 20 bushels per acre. A cornfield on the edge of the Platte Valley in Phelps County, brought to a yield of nearly 35 bushels by pump irrigation at the right time, showed far more than enough benefit to pay for the ground up to the base of tall cottonwoods. The benefited ground here was higher, but not necessarily poorer cornland than the more distant part of the same field. Unirrigated fields, even in the valley, yielded practically nothing.

EFFECT ON ALFALFA

Alfalfa crops have indicated that their manner of growth and quite steady use of water brought from considerable depths make them even more readily influenced than corn. The number of cases carefully measured does not, however, justify an unqualified conclusion.

Benefit from protection is more apparent in alfalfa fields because the deeper roots of the alfalfa can cope successfully with those of trees, and damage from sapping or shading is markedly less than with most field crops. Direct protection benefits have also been unmistakable in one or two cases.

An upland crop measured near Aberdeen, S. Dak., in 1935 showed 60 to 70 percent increase over the field average in the best part of the protected zone, and a total increase on the cut about July 1 equal to the crop which might have been grown on a strip at least 4 times as wide as the height of the trees. Another crop measured in the Platte Valley in Nebraska for the cut of early September showed a well-distributed gain from a single old row of cottonwoods on the south, 60 feet high, equal to the added yield of a strip nearly 100 feet wide.

Considering, in addition to this showing, the fact that alfalfa is frequently winter-killed and is much benefited by snow cover, which can at least in part be insured by frequent, loose windbreaks, it seems that a crop of this kind perhaps justifies more than any other the intensive protection of windbreaks.

EFFECT ON SMALL GRAINS

The record of gains from the protection of small grains from wind is far less convincing, as it comes mainly from unauthenticated reports indicating rather than proving conclusively substantial benefits under certain conditions. The record for 1908 comprised only one wheat field and one barley field showing benefits from windbreaks, and in both cases this was rather plainly a benefit arising from the snow deposited on the fields to an extent sufficient to offset the early-season dryness. During the 1934 drought, failure was too general to permit of any reliable indications of windbreak effectiveness. In 1935, 14 fields measured in July near Aberdeen, S. Dak., failed to show any noticeable effects of protection, because late attacks of stem-rust before harvest reduced average yields to about 12 bushels per acre. It is only possible to say that slight gains in cer-

tain places were barely sufficient on an average to balance losses near the trees. Variations in straw were very similar to those in grain weight, in every field.

In general, it may be pointed out that, since wheat makes most of its development under moderate early-season temperature conditions and is wholly unlike corn in not demanding high temperatures for its vegetative development, the slight addition to temperatures caused by wind reduction may be an inimical factor sufficient to counterbalance any favorable effect of reduced evaporation rate. If this be true, the possibilities of benefit from windbreak planting in the southern small-grain belt should be much less than in the North.

GARDENS RESPOND TO INTENSIVE PROTECTION

Gardens do not lend themselves well to accurate comparisons or scaled measurements, and therefore this discussion is based rather on the evidence of common experience.

It is almost an axiom in many parts of the Plains that good gardens cannot be raised without protection, if not afforded by windbreaks, then by neighboring buildings of the farmstead. The rather striking benefits derived from wind barriers surrounding an acre or two of garden on two or three, or sometimes all sides, raise the question as to whether any of the field protection considered here provides an adequate estimate of the maximum benefits that might be obtained.

Most garden crops are, however, heavy water users as compared with the more common field crops, and therefore probably respond more fully to protection than field crops. Also, where artificial watering cannot be done, they are more definitely dependent for even average productivity on the benefits of trapped snow and on a reduction in evaporation. This is in line with the comparison which has been made above of corn, alfalfa, and small grains.

SUMMARY

It appears that the possibilities of beneficial influence of windbreak protection upon crops are limited in a large measure by the same conditions which determine whether trees grow easily and well, namely, a type of soil and/or the amount of rainfall which insure deep storage and a steady, if not abundant, supply of moisture. Where these conditions exist, the reduction of evaporation rates in protected parts of a field may have practical effects. With less steady soil moisture, the supply cannot be conserved long enough to produce certain benefits. However, it seems likely that long-term benefits from the prevention or reduction of soil blowing, as well as occasional protection of crops from blow-down, may justify such narrow belts as can be successfully maintained, even on many of the hard uplands of the wheat belt where tree-growing is difficult but not impossible.

How much of the farm area may profitably be devoted to windbreak protection must be determined by local conditions. In the Corn Belt, even toward its western edge, and certainly on valley and irrigated lands, the direct crop benefits from windbreaks will justify belts of a width fully equal to their ultimate heights. If

these are planted 20 heights apart, approximately 5 percent of the area can be used for trees without actually reducing farm yields. The planting of 10 percent of farms to trees in the Middle West may not be too high a goal, but may possibly go beyond the point of highest returns. This remains to be determined by crop measurements representing true averages.

In determining the profitable spacing between belts, it is well to point out that few, if any, crop measurements have shown the benefits to be material beyond about 10 times the windbreak height, as indicated by figure 6. If, however, windbreaks are placed 20 heights apart, it is reasonable to suppose that even the middle of the field between them, receiving some protection from two, or from all directions, would generally be benefited appreciably, if not to the fullest extent. A spacing of 20 to 25 heights, therefore, implies no useless overlapping. If the larger of these figures be taken, it means that the following distances should be observed for different types of windbreak:

Windbreak:	*Distance apart*
Osage hedges (20 feet high)	30 rods
Ash and similar upland trees (40 feet high)	60 rods
Cottonwoods on good ground (70 feet high)	120 rods

Of course, in many situations, cottonwood grows very well without making a barrier more than 55 to 60 feet high, and in such cases a spacing of about 80 rods or one-fourth mile seems logical. If belts are placed at these distances, across the path of the most drying winds, an occasional belt at right angles will complete a very snug arrangement for protection.

HOW TO UTILIZE SHADE AND YET PROTECT TREES

How can the farmer have both healthy trees and the benefit of their shade?

There is a natural tendency, where tree growth is scarce, to permit livestock of all kinds to have access to groves, gradually thinning them and opening them to the sun and wind, and finally exterminating the trees almost completely. Observations made during and since the recent drought period have left no doubt that much of the loss of trees from planted groves is the result of grazing and trampling by livestock and that reasonable length of life for trees in the Plains region can be expected only when livestock are wholly or largely excluded from them.

In the hardwood region of Indiana and adjacent States, where conditions are much more favorable for trees than in the Plains States, it is found that the growth of forests is cut in half by grazing use, and at the same time that the value of woods grazing as a means of putting weight on cattle is negligible. Evidently, one cannot have good trees and at the same time utilize the land for pasture. In addition, in the midwestern region there is a strong tendency for the land to return to a grass cover to the entire exclusion of trees, unless the latter are favored in every way.

Trees are injured by almost all domestic animals, from fowls to cattle and horses, principally because they disturb the surface soil and

the protective litter which keeps it moist, and kill the surface roots, which alone are capable of making use of light rains. The elimination of all undergrowth and brush by browsing is a further step toward giving entry to the wind, causing the leaf fall to be blown away and the ground eventually to be dry and hard instead of spongy and moist.

When two interests clash, as they do in this case, there must be compromise. Literally, by utilizing shade without restriction, cattle and other stock destroy it. It goes almost without saying that even the limited use here suggested must be deferred until young plantations are well established and the trees stout enough not to be injured by rubbing. The following possibilities are suggested by means of which the much-needed shade may be had and the damage to the trees be greatly reduced.

1. The idea that land planted to trees can furnish valuable feed should be wholly abandoned, unless the trees have already gone to pieces. Cattle should be admitted to a grove only for short periods in the middle of the day, and in hot, dry weather, when use has relatively little tendency to pack the soil. Hogs and poultry should be entirely excluded. If the grove can be so fenced that livestock are kept out of two or three rows of trees around the edges, it may be possible to retain the lower limbs on these trees, to develop a brush cover, and so maintain that density on the sides which will largely keep the wind out of the entire grove.

2. If the pasture fence is extended only to the edge of the grove on its north side, the necessary noonday shade can be enjoyed with the least possible trampling of any of the tree roots. Browsing and opening of the stand will then be prevented.

3. Best of all is to erect in the pasture, where there is generally a good breeze, an artificial shelter. The Sioux Indians long ago solved the problem of summer comfort by living almost continuously under flat-roofed "bowers" of poles and branches. Thinnings from a 10-year-old planted grove will supply most of the materials needed for such cattle shades, with much less damage than results when stock are allowed to trample the grove.

HOW AND WHAT TO PLANT

Trees planted in any region where natural timber is scarce have many useful aspects, and in some respects serve man's needs better than the natural timber. Frequently, even where there is some natural timber, farmers select the highest hilltops for their farmsteads, in order to have well-drained ground and healthful living conditions, and then surround these exposed farmsteads with trees placed just where they will be most beneficial in furnishing shade and protection from wind.

Planted timber, with adequate protection, may make a substantial addition to the fuel supply, especially useful for summer fires, and may furnish many useful things for the farm, such as fence posts, poles, and even a small volume of rough lumber. These uses are so varied, and depend so directly on the species planted and the rate of growth which the land will support, that it is not the intention

to treat the subject of timber returns in detail in this bulletin. Numerous measurements, however, indicate that land in the prairie-Plains region of the Middle West yields from 1/4 to 1 cord of wood per acre per year, or even slightly more with the fast-growing poplars which thrive in the north. The best yields are generally obtained on the somewhat sandy soils of the region, not necessarily the richest, but those in which a steady, deep moisture supply insures fairly good crops year in and year out.

It is not the intent to go into the details of planting methods, since that subject is covered with great thoroughness by a number of other Farmers' Bulletins and State publications and varies somewhat according to time and place. The degree of care required in preparing and fallowing the land in advance of planting, for example, is considerably greater under very dry conditions than when, or where, moisture is more abundant. Complete protection from stock has already been sufficiently emphasized. The cultivation of the trees for several years after planting is always desirable in order that their gowth may not be suppressed by weeds and in the first year is usually vital to successful establishment.

In connection with the last suggestion, there is much evidence that stands in the prairie-Plains region require reasonably wide spacing as they mature but that close spacing of the young stands has every advantage except that it requires the use of fairly narrow machinery in cultivation. If the trees are spaced not more than 6 by 6 feet, or 6 by 8 feet when planted, the branches will meet sooner, cultivation can be stopped sooner, and better form and height will be developed. During this development, thinnings can and should be made, instead of permitting the slow death of the weaker specimens.

Beyond these general provisions, the next most important item is to select the right planting stock and to handle it with care at least equal to that which one would employ in transplanting tomato or cabbage plants. Evergreen trees, particularly, must never have their roots exposed to dry air or sun.

There are about 100 species of trees and the more important tall shrubs which have been used for planting in the prairie-Plains region, but here are listed only those which by their survival of the recent prolonged drought may be segregated from the "fair-weather" species. The time for any large-scale experimental plantings is largely over in a region where trees cannot easily be grown, yet where their success means so much in improving living conditions.

With a few exceptions, the kinds of trees which succeed best vary somewhat from north to south. It has, therefore, seemed desirable to arrange the species in table 1 according to their suitability in each of five different latitudes, as marked approximately by the boundaries of the Plains States. In this list the trees which grow tallest, or at least more rapidly, are placed first; shorter trees next; and shrubby forms last, corresponding to the positions which they should occupy in forming a most effective windbreak—the tallest trees in the middle and the shorter ones on each side. Where space does not permit so wide a belt, the shorter trees should be placed on the side from which the most important winds are likely to come.

TABLE 1.—*Limited list of most reliable trees suitable for planting in different latitudes* [1]

Common name of tree	North Dakota	South Dakota	Nebraska	Kansas	Oklahoma and north Texas
Tall trees:					
Native cottonwood [2]	G	G	G	G	G
Chinese elm	G	G	G	G	G
Sycamore	X	X	F	G	G
Intermediate trees:					
Black locust [2 3]	X	P	G	G	G
American elm	G	G	G	G	G
Green ash	G	G	G	[3] G	[3] G
Hackberry	G	G	G	G	G
Black or Texas walnut [4] (latter in South only)	X	F	G	G	G
White and golden willows [2]	G	G	F	X	X
Honey locust	X	P	G	G	G
Bur oak	G	G	G	G	F
Post oak	X	X	X	F	G
Russian mulberry	X	X	F	G	G
Osage orange	X	X	G	G	G
Evergreens:					
Ponderosa pine	G	G	G	G	F
Red cedar (Eastern, Rocky Mountain, one-seeded and red-berry junipers) (last two in South)	G	G	G	G	G
Black Hills spruce	G	G	X	X	X
Austrian or Corsican pine	X	F	G	G	G
Blue spruce	F	F	F	F	X
Shrubs:					
Russian olive	G	G	G	G	F
Siberian pea tree (Caragana)	G	G	F	P	X
Wild plums (Chickasaw in South)	G	G	G	G	G
Choke cherry	G	G	G	G	F
Common lilac	G	G	G	F	X
Persian lilac	X	X	X	G	G
Desert flowering willow	X	X	X	F	G
Tamarisk	X	P	F	G	G
Soap-berry and chittamwood (sandy soils only)	X	X	X	G	G

[1] G=good results to be expected; F=fair only; P=poor risk; X=not recommended.
[2] Tree should not be used on dried uplands.
[3] Climatically adapted but subject to borer damage.
[4] Tree should not be used quite as far west as others.

Whether referring to a species which has a very wide range from north to south or to one of more limited usefulness, the purchaser of trees should insist upon stock from seed grown in the latitude in which the trees are to be planted and under climatic conditions similar to those of the planting site, especially with respect to amount of rainfall.

Unfortunately, such information cannot be had in the case of the very popular Chinese elm. The stock obtainable in this country is very much mixed with regard to original source of seed in the Orient. The winter of 1935–36 has demonstrated that some varieties are wholly unhardy in the northern States. In addition, it is well to warn that, since the species has been used in this country only about 20 years, nothing can yet be known as to its long-term value under our conditions.

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